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APPLICATION NUMBER: *60/520,088*
FILING DATE: *November 14, 2003*
RELATED PCT APPLICATION NUMBER: *PCT/US04/37926*

Certified by

Jon W Dudas

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Provisional Application Cover Sheet

Address to:
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This is a request for filing a PROVISIONAL APPLICATION under 37 C.F.R. § 1.53(b)(2).

Docket Number Q3312	Type a plus sign (+) inside this box	+

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Title of the Invention (280 Characters Maximum)

Method and Device for Treating Osteoarthritis and Cartilage Diseases, Defects, and Injuries to the Human Hip

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Enclosed Application Parts (*check all that apply*)

[X] Specification *Number of pages:* 20 [ ] Small Entity Statement

[ ] Drawing(s) *Number of sheets:* [ ] Other (specify)

Method of Payment (*check one*)

[ ] Our Check No. ____ is enclosed to cover the Provisional filing fees. A duplicate copy of this sheet is enclosed. [X] The Commissioner is hereby authorized to charge filing fees and credit Deposit Account No. 13-2489. A duplicate copy of this sheet is enclosed. [ ] Payment by credit card. Form PTO-2028 is attached.	Provisional Filing Fee Amount ($)	$ 80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

[ ] No
[ ] Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

Signature: Carl T. Brighton Date: 11/12/03
Typed or Printed Name: Carl Brighton

[ ] Additional inventors are being named on separately numbered sheets attached hereto.

PROVISIONAL APPLICATION FILING ONLY

PROVISIONAL APPLICATION SUBMISSION TO USPTO – CONTENTS PAGE

Penn Docket Number : Q3312

First-named Inventor : Brighton

Submission Date : 11/14/03

Prepared by : Matt Thomas

CONTENTS LISTED IN ORDER :

Total Number of Pages : 20

Q3312 10/LP

Title of Invention: Method and Device for Treating Osteoarthritis, and Cartilage Disease, Defects, and Injuries in the Human Hip.

Inventors: Carl T. Brighton and Solomon R. Pollack

Field of Invention

The present invention is directed to the method of determining the voltage and current output required for the application of specific and selective electric and electromagnetic signals to diseased articular cartilage in the treatment of osteoarthritis, cartilage defects due to trauma or sports injuries, or as an adjunct with other therapies (e.g., cell transplantation, tissue-engineered scaffolds, growth factors, etc.) for treating cartilage defects in the human hip joint and a device for delivering such signals to a patient's hip.

Background of the Invention

The bioelectrical interactions and activity believed to be present in a variety of biological tissues and cells are one of the least understood of the physiological processes. However, there has recently been much research into these interactions and activities related to the growth and repair of certain tissues and cells. In particular, there has been considerable interest in stimulation by electric and electromagnetic fields and their effect on the growth and repair of bone and cartilage. Scientists believe that such research might be useful in the development of new treatments for a variety of medical problems.

Osteoarthritis, also known as degenerative joint disease, is characterized by degeneration of articular cartilage as well as proliferation and remodeling of subchondral bone. The usual symptoms are stiffness, limitation of motion, and pain. Osteoarthritis is the most common form of arthritis, and prevalence rates increase markedly with age. It has been shown that elderly patients with self-reported osteoarthritis visit doctors twice as frequently as their unaffected peers. Such patients also experience more days of restricted activity and bed confinement compared to others in their age group. In one study, the majority of symptomatic patients became significantly disabled during an 8-year follow-up period (**Massardo et al.**, *Ann Rheum Dis* 48:893-897, 1989).

Nonsteroidal anti-inflammatory drugs (NSAIDs) remain the primary treatment modality for osteoarthritis. It is unknown whether the efficacy of NSAIDs is dependent upon their analgesic or anti-inflammatory properties or the slowing of degenerative processes in the cartilage. There is also a concern that NSAIDs may be deleterious to patients. For example, NSAIDs display well-known toxic effects in the stomach, gastrointestinal tract, liver and kidney. Moreover, aspirin inhibits proteoglycan synthesis and normal cartilaginous repair processes in animals. One study in humans also suggested that indomethacin might accelerate breakdown of hip cartilage. All adverse effects appear more commonly in the elderly—the very population most susceptible to osteoarthritis.

In the disease commonly known as osteoporosis, bone demineralizes and becomes abnormally rarefied. Bone comprises an organic component of cells and matrix as well as an inorganic or mineral component. The cells and matrix comprise a framework of collagenous fibers that is impregnated with the mineral component of calcium phosphate (85%) and calcium carbonate

(10%) that imparts rigidity to bone. While osteoporosis is generally thought to afflict the elderly, certain types of osteoporosis may affect persons of all ages whose bones are not subject to functional stress. In such cases, patients may experience a significant loss of cortical and cancellous bone during prolonged periods of immobilization. Elderly patients are known to experience bone loss due to disuse when immobilized after fracture of a bone; this may ultimately lead to a secondary fracture in an already osteoporotic skeleton. Diminished bone density may lead to collapse of vertebrae, fractures of hips, lower arms, wrists and ankles, as well as incapacitating pains. Alternative non-surgical therapies for such diseases are needed.

Pulsed electromagnetic fields (PEMFs) and capacitive coupling (CC) have been used widely to treat non-healing fractures and related problems in bone healing since approval by the Food and Drug Administration in 1979. The original basis for the trial of this form of therapy was the observation that physical stress on bone causes the appearance of tiny electric currents that, along with mechanical strain, were thought to be the mechanisms underlying transduction of the physical stress into a signal that promotes bone formation. Along with direct electric field stimulation that was successful in the treatment of nonunion, noninvasive technologies using PEMF and CC (where the electrodes are placed on the skin in the treatment zone) were also found to be effective. PEMFs generate small, induced currents (Faraday currents) in the highly conductive extracellular fluid, while CC directly causes currents in the tissues; both PEMFs and CC thereby mimic endogenous electrical currents.

The endogenous electrical currents, originally thought to be due to phenomena occurring at the surface of crystals in the bone, have been shown to be due primarily to movement of fluid containing electrolytes in channels of the bone containing organic constituents with fixed negative charges, generating what are called "streaming potentials." Studies of electrical phenomena in cartilage have demonstrated a mechanical-electrical transduction mechanism that resembles those described in bone, appearing when cartilage is mechanically compressed, causing movement of fluid and electrolytes over the surface of fixed negative charges in the proteoglycans and collagen in the cartilage matrix. These streaming potentials apparently serve a purpose in cartilage similar to that in bone, and, along with mechanical strain, lead to signal transduction that is capable of stimulating chondrocyte synthesis of matrix components.

The main application of direct current, CC, and PEMFs has been in orthopaedics in the healing of nonunion bone fractures (**Brighton et al.** *J Bone Joint Surg* 1981;63:2-13; **Brighton and Pollack** *J Bone Joint Surg* 1985;67:577-585; **Bassett et al.** *Crit Rev Biomed Eng* 1989;17:451-529; **Bassett et al.** *J Am Med Assoc* 1982;247:623-628). Clinical responses have been reported in avascular necrosis of hips in adults and Legg-Perthe's disease in children (**Bassett et al.** *Clin Orthop* 1989;246:172-176; **Aaron et al.** *Clin Orthop* 1989;249:209-218; **Harrison et al.** *J Pediatr Orthop* 1984;4:579-584, 1984). It has also been shown that PEMFs (**Mooney.** *Spine* 1990;15:708-712) and CC (**Goodwin et al.** *Spine* 1999;24:1349-135) can significantly increase the success rate of lumbar fusions. There are also reports of augmentation of peripheral nerve regeneration and function and promotions of angiogenesis (**Bassett.** *Bioessays* 1987;6:36-42). Patients with persistent rotator cuff tendonitis refractory to steroid injection and other conventional measures showed significant benefit compared with placebo treated patients (**Binder et al.** *Lancet* 1984;695-698). Finally, Brighton et al., have shown in rats the ability of an appropriate CC electric field to both prevent and reverse vertebral osteoporosis in the lumbar

spine (**Brighton et al.** *J Orthop Res* 1988;6:676-684; **Brighton et al.** *J Bone Joint Surg* 1989;71:228-236).

More recently, research in this area has focused on the effects that stimulation has on tissues and cells. For example, it has been conjectured that direct currents do not penetrate cellular membranes and that control is achieved via extracellular matrix differentiation (**Grodzinsky** *Crit Rev Biomed Eng* 1983;9:133). In contrast to direct currents, it has been reported that PEMFs can penetrate cell membranes and either stimulate them or directly affect intracellular organelles. An examination of the effect of PEMFs on extracellular matrices and *in vivo* endochondral ossification found increased synthesis of cartilage molecules and maturation of bone trabeculae (**Aaron et al.** *J Bone Miner Res* 1998;4:227-233). More recently, it was reported (**Lorich et al.** *Clin Orthop Related Res* 1998;350:246-256) that signal transduction of a capacitively coupled electric signal is via voltage-gated calcium channels, leading to an increase in cytosolic calcium with a subsequent increase in activated (cytoskeletal) calmodulin.

Much research has been performed using tissue culture techniques in order to understand the mechanisms of response. In one study, it was found that electric fields increased [^{3}H]thymidine incorporation into the DNA of chondrocytes, supporting the notion that Na^+ and Ca^{+2} fluxes generated by electrical stimulation trigger DNA synthesis (**Rodan et al.** *Science* 1978;199:690-692). Studies have found changes in the second messenger, cAMP, and cytoskeletal rearrangements due to electrical perturbations (**Ryaby et al.** *Trans BRAGS* 1986;6; **Jones et al.** *Trans. BRAGS* 6:51, 1986; **Brighton and Townsend** *J Orthop Res* 1988;6:552-558). Other studies have found effects on glycosaminoglycan, sulfation, hyaluronic acid, lysozyme activity and polypeptide sequences (**Norton et al.** *J Orthop Res* 1988;6:685-689; **Goodman et al.** *Proc Natl Acad Sci* 1988;85:3928-3932).

It was reported in 1996 by one of the present inventors (CTB) that a cyclic, biaxial 0.17% mechanical strain produces a significant increase in TGF-β_1 mRNA in cultured MC3T3-E1 bone cells (**Zhuang et al.** *Biochem Biophys Res Commun* 1996;229:449-453). Several significant studies followed in 1997. In one study it was reported that the same cyclic, biaxial 0.17% mechanical strain produced a significant increase in PDGF-A mRNA in similar bone cells (**Wang et al.** *Biochem Mol Biol Int* 1997;43:339-346). It was also reported that a 60 kHz capacitively coupled electric field of 20 mV/cm produced a significant increase in TGF-β_1 mRNA in similar bone cells (**Zhuang et al.** *Biochem Biophys Res Commun* 1997;237:225-229). However, the effect such a field would have on other genes has not been reported in the literature.

In the above referenced parent patent application, entitled *"Regulation of Genes Via Application of Specific and Selective Electrical and Electromagnetic Signals,"* methods were disclosed for determining the specific and selective electrical and electromagnetic signals for use in creating specific and selective fields for regulating target genes of diseased or injured tissues. The present invention builds upon the technique described therein by describing the method of determining the voltage and current output required, and the corresponding apparatus for delivering specific and selective electrical and electromagnetic signals to the human hip joints in patients afflicted with osteoarthritis and other cartilage defects, diseases and injuries.

Summary of the Invention

The present invention related to treating osteoarthritis and other cartilage diseases, defects, and injuries in human hip joints via the application of specific and selective fields generated by specific and selective electric and/or electromagnetic signals. The invention includes a method of determining the voltage and current of the signal to apply to electrodes or to a solenoid or to at least one coil applied to the hip for treatment.

More particularly, the invention relates to a method of treating diseased tissue in a human through the application of a specific and selective electric or electromagnetic field to diseased tissue in a human, including osteoarthritis and other cartilage diseases, defects and injuries in the hip; or used as an adjunct with other therapies (cell transplantation, tissue-engineered scaffolds, growth factors, etc.) in treating cartilage defects in the human hip. The method includes the steps of determining the voltage and current output that produces the desired 20 mV/cm electric field in the articular cartilage of the human hip joint, the preferred embodiment, and other voltage and current values for other effective electric field amplitudes thought or known to be effective. The method includes constructing an anatomic model of the human hip joint and translating the anatomic model to an analytical model of the hip in which the dimensions for the tissues encountered from skin (anterior) through fat and skin (posterior) are determined. Planar circuits were then constructed in which the various tissue conductivities, impedances and current flow were used in calculating the voltage and current required to be applied to surface electrodes placed anteriorly and posteriorly on the skin covering the hip in order to produce an electric field at 20 mV/cm in articular cartilage of the hip joint at a frequency of 60 kHz. One knowledgeable in the field could perform the same analysis at other frequencies, adjust the tissue impedances to their values at the new frequency and obtain different values for the ranges of the electrical field and current density at any chosen frequency or set of frequencies.

The invention also includes a method and a device for treating diseased tissue (such as osteoarthritis), defective or injured tissue in a human hip joint through the application of a specific and selective electric or electromagnetic field to the afflicted tissue in the human hip joint. Such a device in accordance with a capacitive coupling embodiment of the invention includes at least two electrodes adapted for application in the proximity of a patient's hip joint and a signal generator that generates electric signals for application to the electrodes so as to produce an electric field of amplitude of 20 mV/cm ± 15% and a current density of 120 $\mu A/cm^2$ ± 15% within the synovium and articular cartilage of the patient's hip joint. An inductive coupling embodiment of the invention includes a coil(s) or solenoid adapted and configured to receive the electric signals to produce these electric fields. Preferably, the signal generator provides one of a plurality of output electric signals with a voltage selected by a user in accordance with a size of the human hip joint. Larger hip joints receive signals of larger voltages.

These and other aspects of the present invention will be elucidated in the following detailed description of the invention.

Brief Description of the Drawings

The present invention will be apparent from the following detailed description of the invention in conjunction with the accompanying drawing:

Figure 1 illustrates an anatomic model of the human hip joint showing all the important tissues and structures through which the current passes between the anterior and posterior surface electrodes placed on skin.

Figure 2 illustrates an analytical model of the human hip joint from which size parameters are determined for each of the tissues and structures indicated (see Tables 1A and 2).

Figure 3A illustrates a planar circuit model of the human hip joint showing circumferential flow of current through the fat layers (I_3) plus leakage flow of current through the muscle and other soft tissue (I_4), plus current flow across the hip joint (I_2). The impedance (Z) compartments are also shown (see Table 2 for definitions of symbols).

Figure 3B illustrates a planar circuit showing in detail the current flow and impedances across the hip joint (Z_{T1}). Z = impedance; I = current. (See Table 2 for definitions of symbols).

Figure 4 illustrates schematically the three currents that were calculated in determining the output current and voltage required to produce a 20 mV/cm field in the articular cartilage of the hip joint. The three currents are the circumferential current, the leakage current, and the current flowing through the hip joint.

Figure 5 illustrates electrode placement on the skin that is required to produce the desired electric field in the hip joint.

Detailed Description of Preferred Embodiments of the Invention

The invention will be described with reference to Figures 1-5 and Tables 1-2. Those skilled in the art will appreciate that the description given herein with respect to these figures is for exemplary purposes only and is not intended in any way to limit the scope of the invention. All questions regarding the scope of the invention may be resolved by referring to the appended claims.

Definitions:

As used herein, the term "signal" is used to refer to a variety of signals including mechanical signals, ultrasound signals, electromagnetic signals, and electric signals outputted by a device.

As used herein, the term "field" refers to an electric field within a targeted tissue, whether it is a combined field or a pulsed electromagnetic field, or generated by direct current, capacitive coupling, or inductive coupling.

Description of Illustrated Embodiments

We now determine the electric field amplitude and current density obtained in the cartilage space in a hip joint when electrodes are placed posteriorly and anteriorly, and a voltage is applied causing a current to flow through the body. This situation is shown in Figure 1. Specifically, we take the frequency of a sine wave voltage to be 60 kHz, but the methodology can be applied to any frequency as long as the electrical properties of the tissues are chosen for those frequencies. We seek to know the voltage and the current to be applied to the electrodes in order to obtain in the cartilage of the hip joint a therapeutic electric field amplitude of 20 mV/cm, the preferred embodiment, and voltage and current values for other effective electric field amplitudes known to be effective. It is clear from Figure 1 that patients of different sizes may require different applied voltages and currents to achieve the therapeutic electric field amplitudes. Accordingly

this calculation will model the patient for four (4) different size classifications. The essential geometric model parameters for these four sizes along with the relevant electrical properties of all tissue types are shown in Tables 1A and 1B. The electrodes are taken to be 2" × 2" square and the currents are calculated by considering the current flow through the patient's body for a 2" × 2" rectangle from one electrode to the other plus the circumferential flow of current through the fat layer plus the leakage current that flows through the muscle and other soft tissues outside of the 2" × 2" rectangle but excluding the circumferential current in the fat layer. These currents are shown in Figures 3 and 4. The impedances of the tissue compartments through which the current I_2 (Figure 3) flows are shown in Figure 3B. A line drawing showing patient electrode placement is presented in Figure 5.

The definitions of terms in Figures 2, 3A, 3B and 4 are shown in Table 2. Each impedance labeled in Figures 3 and 4 was calculated using the relationship

$$Z = \frac{1}{\sigma} \circ \frac{Length}{Area} \qquad \textit{(Equation 1)}$$

Where *Length* is the dimension of the tissue in the direction of the current flow, and *Area* is the cross-sectional area of the tissue perpendicular to the direction of current flow.

The impedances were then calculated using Equation 1, the dimensions in Table 1A and the conductivities in Table 1B. Using standard lump circuit analysis for series/parallel impedances, the total current, I_1 (Figure 3A) that must flow from the electrodes was calculated for each patient classification for a voltage applied to the electrodes. In addition, I_2, the current flow through the muscle-femur-cartilage-muscle layers; the current I_3, the current flowing circumferentially through the fat layer and I_4, the leakage currents, were also calculated. This enabled the calculation of the current through the cartilage, $I_{cartilage}$, and the current density, $J_{cartilage}$, from which the electric field amplitude in the cartilage, $E_{cartilage}$, could be computed from the equation

$$J_{cartilage} = \sigma_{cartilage} \circ E_{cartilage} \qquad \textit{(Equation 2)}$$

where $J_{cartilage}$ and $E_{cartilage}$ are described above and $\sigma_{cartilage}$ is the electrical conductivity of the cartilage as shown in Table 1B. These results are summarized in Table 3. From Table 3 we see that for an applied voltage of approximately 5 V peak-to-peak sine wave at 60 kHz, we obtain electric fields of 20 mV/cm ± 3.5 mV/cm for the small, medium and large patient, but not for the extra-large patient. The extra-large patient requires a voltage that is approximately twice that required for the other three patient sizes.

We are now in a position to calculate the devise current to the 2" × 2" electrodes in order to achieve a 20 mV/cm electric field amplitude in the cartilage. These values, and the approximate device voltages that achieve these device currents are shown below along with the current and current density in the cartilage when the applied voltage is as shown for each patient size:

Device Voltage and Current Required to Apply 20 mV/cm Electric Field to Cartilage in the Human Hip

Patient Size	Device Voltage	Device Current (2" x 2" electrode)	Electrode Current Density
Small	4.3 V_{p-p}	26.8 mA	1.04 mA/cm^2
Medium	4.5 V_{p-p}	31.6 mA	1.23 mA/cm^2
Large	5.7 V_{p-p}	32.0 mA	1.24 mA/cm^2
Extra Large	10.2 V_{p-p}	52.1 mA	2.02 mA/cm^2

Cartilage Current and Current Density When a 20 mV/cm Electric Field is Applied to the Cartilage of the Human Hip

Patient Size	Cartilage Current	Cartilage Current Density
Small	0.15 mA	120 μA/cm^2
Medium	0.15 mA	120 μA/cm^2
Large	0.15 mA	120 μA/cm^2
Extra Large	0.15 mA	127 μA/cm^2

It is noted that for extra-large patients, the current density value at the electrodes, 2.02 mA/cm^2, is at the maximum value and should not be exceeded.

It is understood that patients with a specific size, i.e., electrode-to-electrode dimension, may have tissue compartment sizes and/or skin impedance values that differ from those modeled here. Therefore, devices that power the electrodes should have output variability to increase the peak-to-peak voltage to achieve the desired electrode current (density).

The current (or electric field) that flows through the cartilage of the hip when a voltage is applied to the electrodes on the skin is determined by the impedances shown in Figures 3A and 3B. For a given patient size, the dimensions of various tissue compartments (and therefore their impedances) can vary so that the current that actually flows through the cartilage could be higher or lower than the values shown for an applied Device Voltage as shown above. Taking reasonable variations in dimensions of the tissue compartments for each patient size we conclude that for a given device voltage, the cartilage current (and therefore the cartilage electric field) could differ by ±15%. Therefore, in order to account for this variation, and to account for the variation of skin electrical impedance from patient to patient, the device should be designed to apply the device current value plus or minus 15% to a pair of 2" x 2" electrodes.

What is claimed is:

1. A method of treating disease tissue in a human through the application of a specific and selective electric or electromagnetic field to the disease tissue in the human, comprising the steps of:
    a. Determining the voltage and current output that produces a 20 mV/cm electric field in the diseased tissue of the human;

b. Constructing an anatomic model of human diseased tissue showing all the pertinent tissues and structures through which the current passes between the skin overlying one side of the diseased tissue through the skin on the opposite side of the diseased tissue;
c. Constructing an analytic model of the diseased tissue from which size parameters are determined for each of the tissues and structures through which the current passes between the anterior and posterior skin surfaces enclosing the diseased tissue;
d. Constructing a planar circuit model of the diseased tissue in order to determine the circumferential flow of current through the fat layer, plus leakage flow of current through the muscle and other soft tissue, plus current flow across the diseased tissue;
e. Constructing a detailed planar circuit model of the diseased tissue giving the impedance and current flow in detail of all the structures and tissues through which the current must flow to achieve a 20 mV/cm electric field in the diseased tissue;
f. Computing the electric field amplitude (20 mV/cm) in the diseased tissue as equal to the targeted diseased tissue current density divided by the targeted diseased tissue conductivity;
g. Applying the scaled voltage and current to the diseased tissue of the human.

2. The method of claim 1 wherein the scaled voltage and current applying step comprises the step of applying the scaled voltage and current to the human using two electrodes in the case of capacitive coupling.
3. The method of claim 1 wherein the scaled voltage and current applying step comprises the step of applying the scaled voltage and current to the human using a solenoid or coil(s) in the case of inductive coupling.
4. The method of claim 1 wherein the scaled voltage and current applying step comprises the step of determining the voltage and current output that produces a 20 mV/cm electric field in the tissues of the diseased human hip.
5. The method of claim 1 wherein the scaled voltage and current applying step comprises the step of constructing an anatomic model of the human hip.
6. The method of claim 1 wherein the scaled voltage and current applying step comprises the step of constructing an analytic model of the diseased human hip from which size parameters are determined for each of the tissues and structures through which the current passes between the anterior and posterior skin surfaces enclosing the human hip.
7. The method of claim 1 wherein the scaled voltage and current applying step comprises the step of constructing a planar circuit model of the human hip in order to determine the circumferential flow of current through the fat layer, the leakage flow of current through the muscle and other soft tissue, and the current flow across and through the human hip.
8. The method of claim 1 wherein the scaled voltage and current applying step comprises the step of constructing a detailed planar circuit model of the human hip giving the impedance and current flow in detail of all the tissues and structures through which the current must flow to achieve a 20 mV/cm electric field in the human hip.

9. The method of claim 1 wherein the scaled voltage and current applying step comprises the set of computing the desired electric field amplitude (20 mV/cm) in the diseased human hip as equal to the current density in the tissues of the hip divided by the conductivity of the tissues in the hip.
10. The method of claim 1 wherein the scaled voltage and current are applied to the diseased human hip.
11. A device for treating diseased tissue in the human hip joint through the application of a specific and selective electric or electromagnetic field to the diseased or injured tissue in the human hip joint comprising:
    a. One of (a) at least two electrodes, in the case of capacitive coupling, adapted for application in the proximity of a patient's hip joint; and (b) a solenoid or at least one coil, in the case of inductive coupling, adapted for application in the same proximity of a patient's hip joint;
    b. A signal generator that generates electric signals for application to the electrodes, the solenoid, or at least one coil so as to produce an electric field of approximately 20 mV/cm ± 15% and a current density range of approximately 120 $\mu A/cm^2$ ± 15% within the synovium and articular cartilage of the patient's hip joint.
12. A device for treating osteoarthritis, cartilage defects due to trauma or sports injury, or used as an adjunct with other therapies for treating cartilage defects in a human hip joint through the application of specific and selective electric or electromagnetic field to the afflicted tissue in the human hip joint, comprising:
    a. One of (a) at least two electrodes on the surface of the skin and (b) a solenoid or at least one coil located external to the skin adapted for application in the proximity of a patient's hip joint.
    b. A signal generator that generates electric signals for application to the electrodes, the solenoid, or at least one coil so as to produce an electric field range of approximately 20 mV/cm ± 15% and a current density range of approximately 120 $\mu A/cm^2$ ± 15% within the synovium and articular cartilage of the patient's hip joint.
13. A device as in claim 12, wherein the signal generator provides one of the plurality of output electric signals with a size of the human hip joint and its surrounding soft tissue and skin.
14. A device as in claim 13, wherein one of the plurality of output electrical signals of the signal generator for a 60 kHz frequency has a voltage of approximately 4.3 V_{p-p} ± 10% for a small size hip joint.
15. A device as in claim 13, wherein one of the plurality of output electrical signals of the signal generator for a 60 kHz frequency has a voltage of approximately 4.5 V_{p-p} ± 10% for a medium sized hip joint.
16. A device as in claim 13, wherein one of the plurality of output electrical signals of the signal generator for a 60 kHz frequency has a voltage of approximately 5.7 V_{p-p} ± 10% for a large sized hip joint.
17. A device as in claim 13, wherein one of the plurality of output electrical signals of the signal generator for a 60 kHz frequency has a voltage of approximately 10.2 V_{p-p} ± 10% for a extra large sized hip joint.

Abstract of the Disclosure

A method of determining the voltage and current required for the application of specific and selective electric and electromagnetic signals to diseased articular cartilage in the treatment of osteoarthritis, cartilage defects due to trauma or sports injury, or used as an adjunct with other therapies (cell transplantation, tissue-engineered scaffold, growth factors, etc.) for treating cartilage defects in the human hip joint and a device for delivering such signals to a patient's hip. Anatomic, analytical, and planar circuit models are developed to determining the impedances, conductivities, and current flows in the human hip joint and its surrounding soft tissues and skin that are required to produce a 20 mV/cm electric field in the synovium and articular cartilage of the human hip. The voltage of the signal applied to the surface electrodes or to a coil(s) or solenoid is varied based on the size of the hip joint; larger hip joints require larger voltages to generate the effective electric field.

TABLE 1A. Size Parameters for Four Patient Classifications

Measurement	*Patient Classification*			
	Small (m)	**Medium (m)**	**Large (m)**	**Extra-Large (m)**
Electrode-to electrode distance (D*)	0.1524	0.18	0.21	0.305
Fat layer thickness (F*)	0.00635	0.00762	0.0222	0.699
Fat layer width	0.051	0.051	0.051	0.051
Muscle (M_3*) length	0.051	0.0635	0.0635	0.0635
Muscle (M_3*) width	0.051	0.051	0.051	0.051
Muscle (M_4*) length	0.0635	0.0762	0.0762	0.0762
Muscle (M_4*) width	0.0254	0.0254	0.0254	0.0254
Muscle (M_8*) length	0.0254	0.0254	0.0254	0.0254
Muscle (M_8*) width	0.051	0.051	0.051	0.051
Cartilage junction length	0.08	0.08	0.08	0.08
Cartilage junction width	0.0127	0.0127	0.0127	0.0127
Femoral head radius (R*)	0.0254	0.0254	0.0254	0.0254
Acetabular thickness (B*)	0.015	0.015	0.015	0.015
Acetabular width	0.04	0.04	0.04	0.04

*See Figure 2

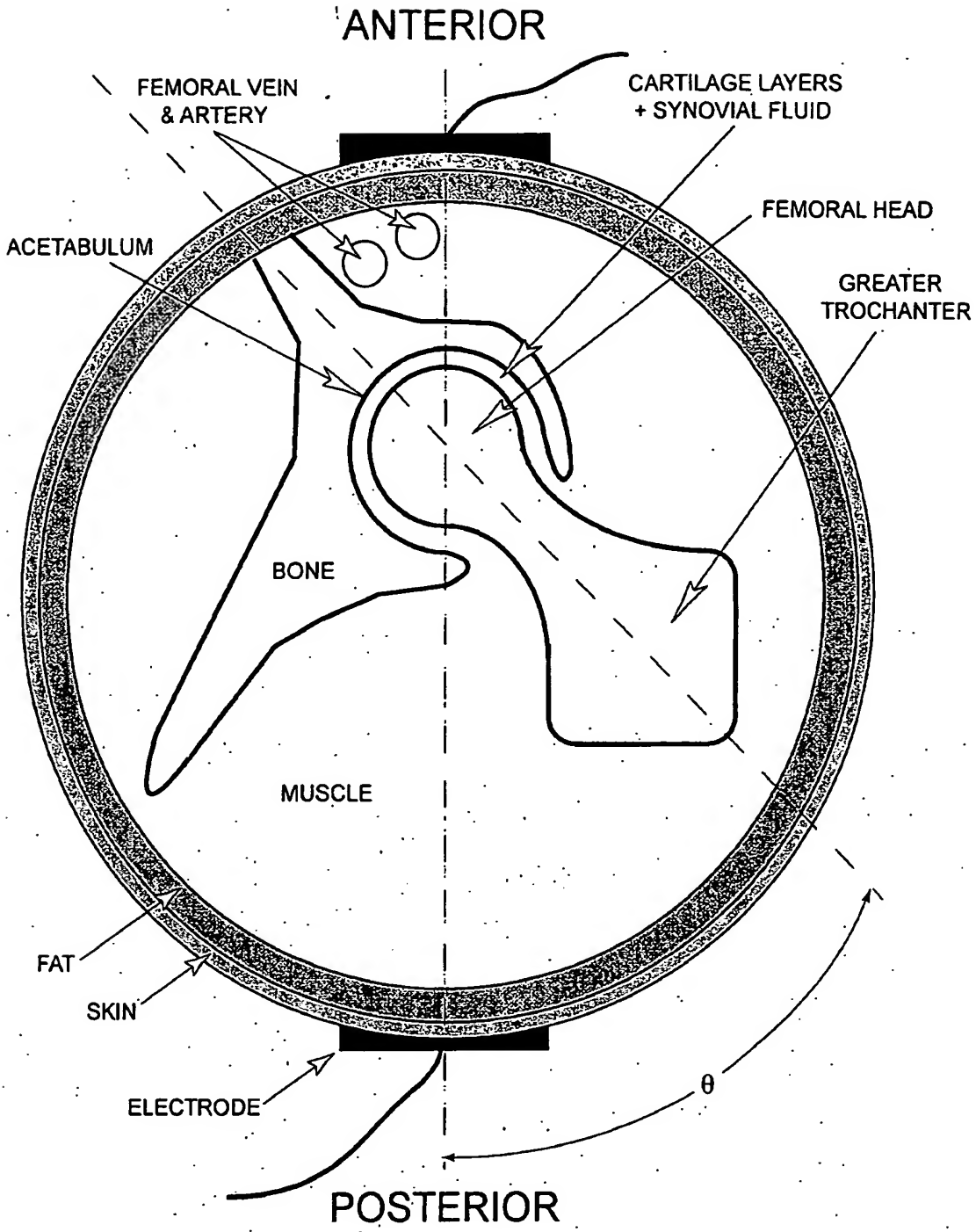
TABLE 1B. Electrical Conductivities

TISSUE	CONDUCTIVITY
Fat	0.02 S/m
Muscle	0.45 S/m
Bone	0.01 S/m
Cartilage	0.6 S/m
Skin Admittance	3×10^{-3} S/cm^2

TABLE 2. Definitions of dimensions and symbols shown in Figures 2 and 3

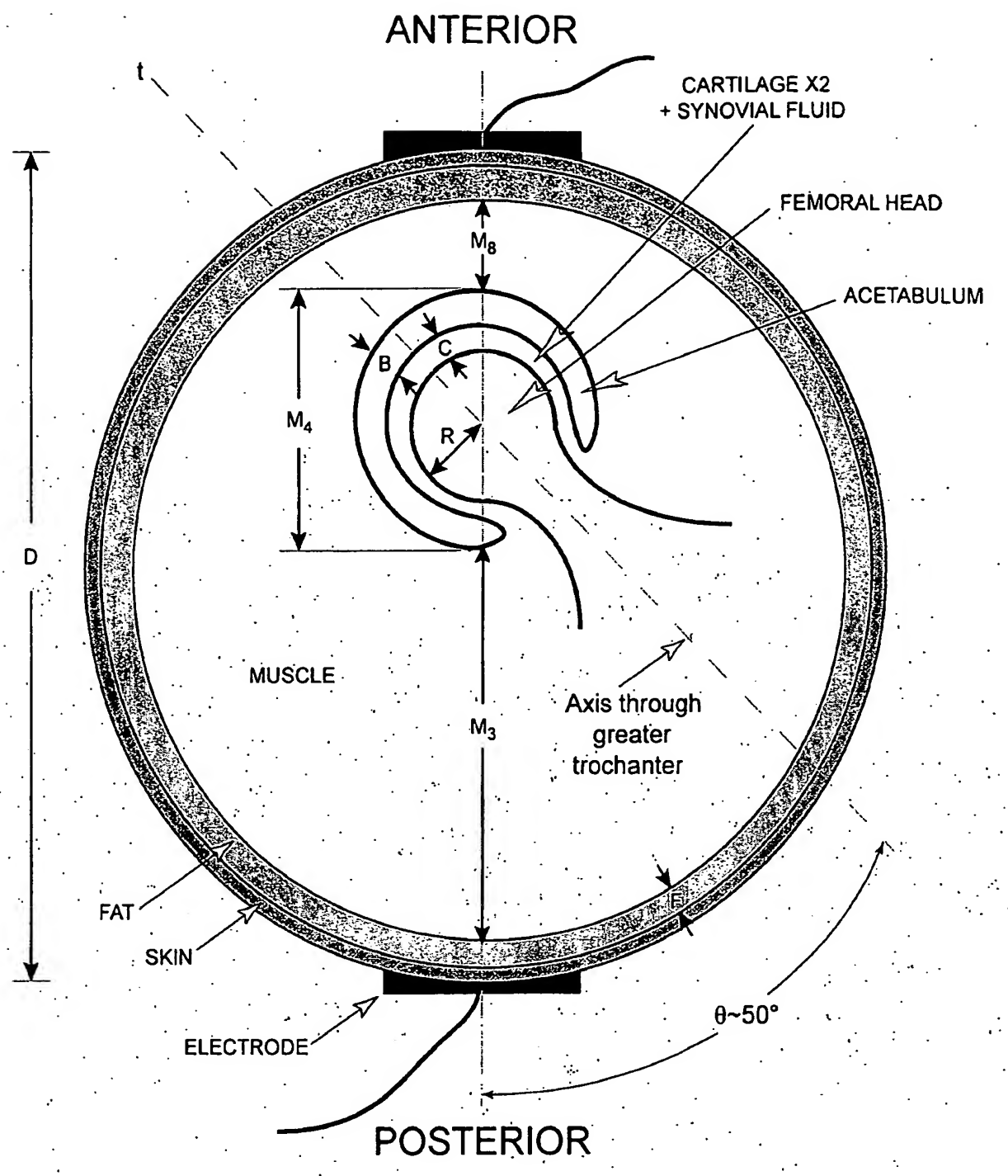
D = electrode to electrode distance
F = fat layer thickness
M = muscle: M_3 = distance (thickness) of muscle from posterior fat layer to posterior acetabulum M_4 = distance (thickness) of muscle from posterior acetabulum to anterior acetabulum M_8 = distance (thickness) of muscle from anterior acetabulum to anterior fat layer
Z = impedance: Z_1 = impedance of skin Z_2 = impedance of fat Z_3 = impedance of muscle posterior to the acetabulum Z_4 = impedance of the muscle around the hip joint Z_{FH} { Z_5 = impedance of bone (acetabulum); Z_6 = impedance of bone (femoral head); Z_7 = impedance of articular cartilage-synovium } Z_8 = impedance of muscle anterior to the acetabulum Z_{T_1} = impedance across the hip joint; i.e., the combined impedance from Point A to Point B in Figure 3B
I = current: I_{total} = total current flowing from electrode to electrode I_{FH} = current flowing through hip joint I_4 = current flowing through muscle I_6 = current flowing through femoral head I_7 = current flowing through articular cartilage
B = Bone (acetabulum) thickness
C = cartilage-synovium thickness
R = radius of femoral head
J = current density (A/cm^2)
E = electric field (V/cm)

FIGURE 1



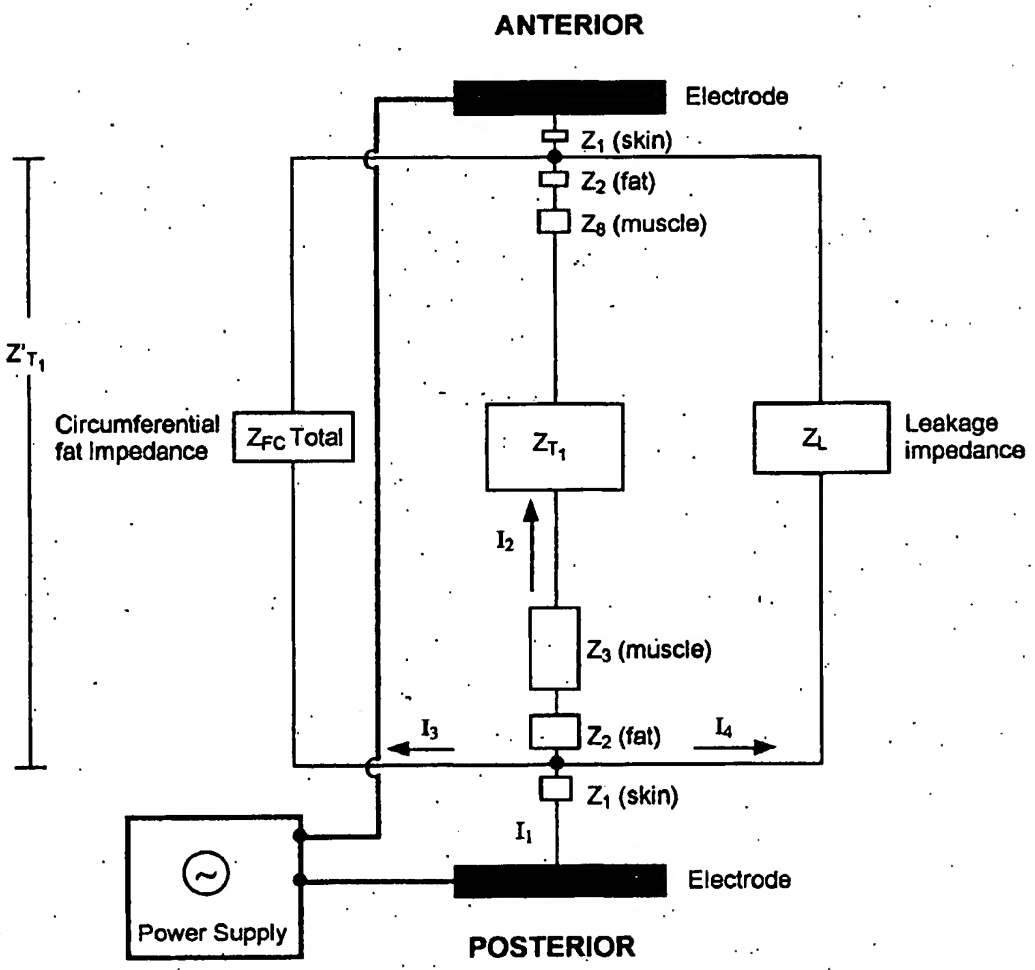
ANATOMIC MODEL

FIGURE 2



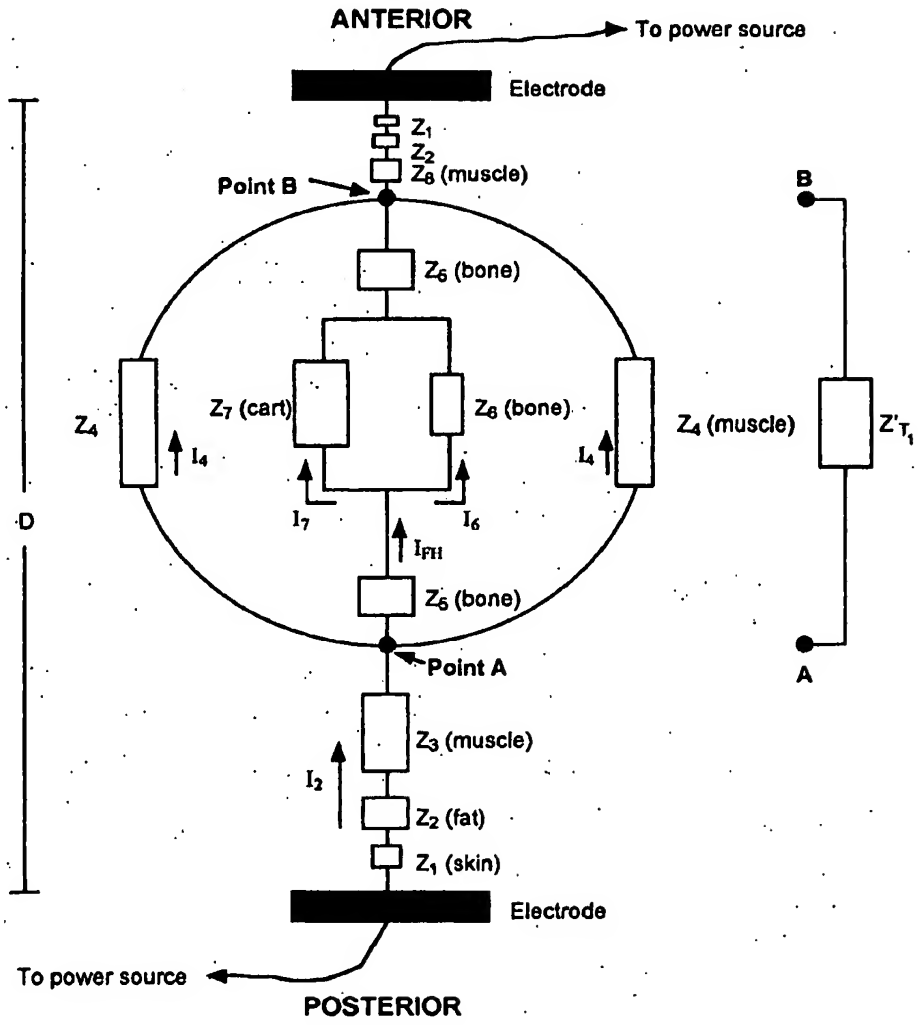
ANALYTICAL MODEL

FIGURE 3A



PLANAR CIRCUIT MODEL WITH CIRCUMFERENTIAL FLOWS

FIGURE 3B



PLANAR CIRCUIT MODEL SHOWING
Z_{T_1} DETAIL FROM FIGURE 3A

FIGURE 4

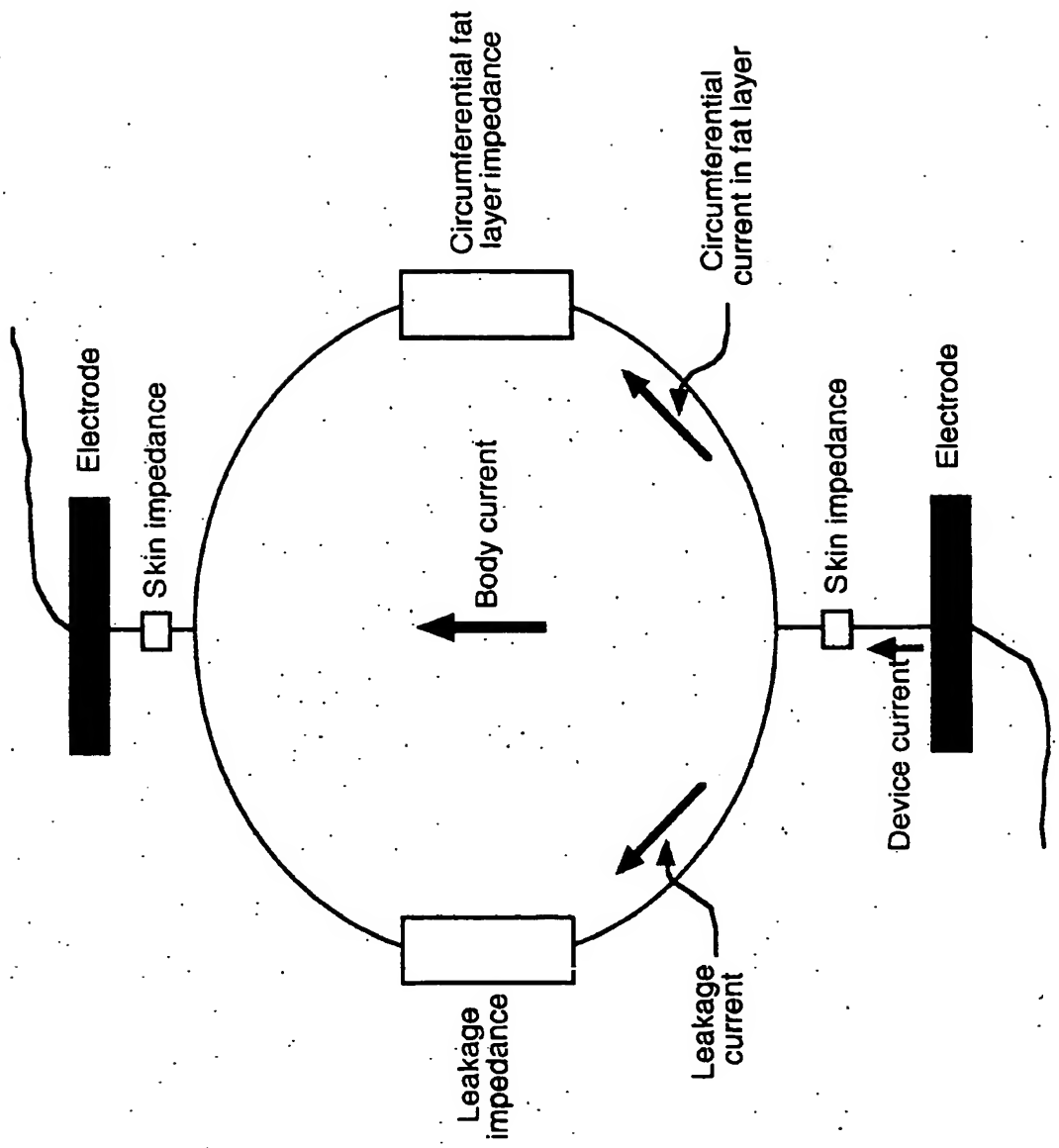
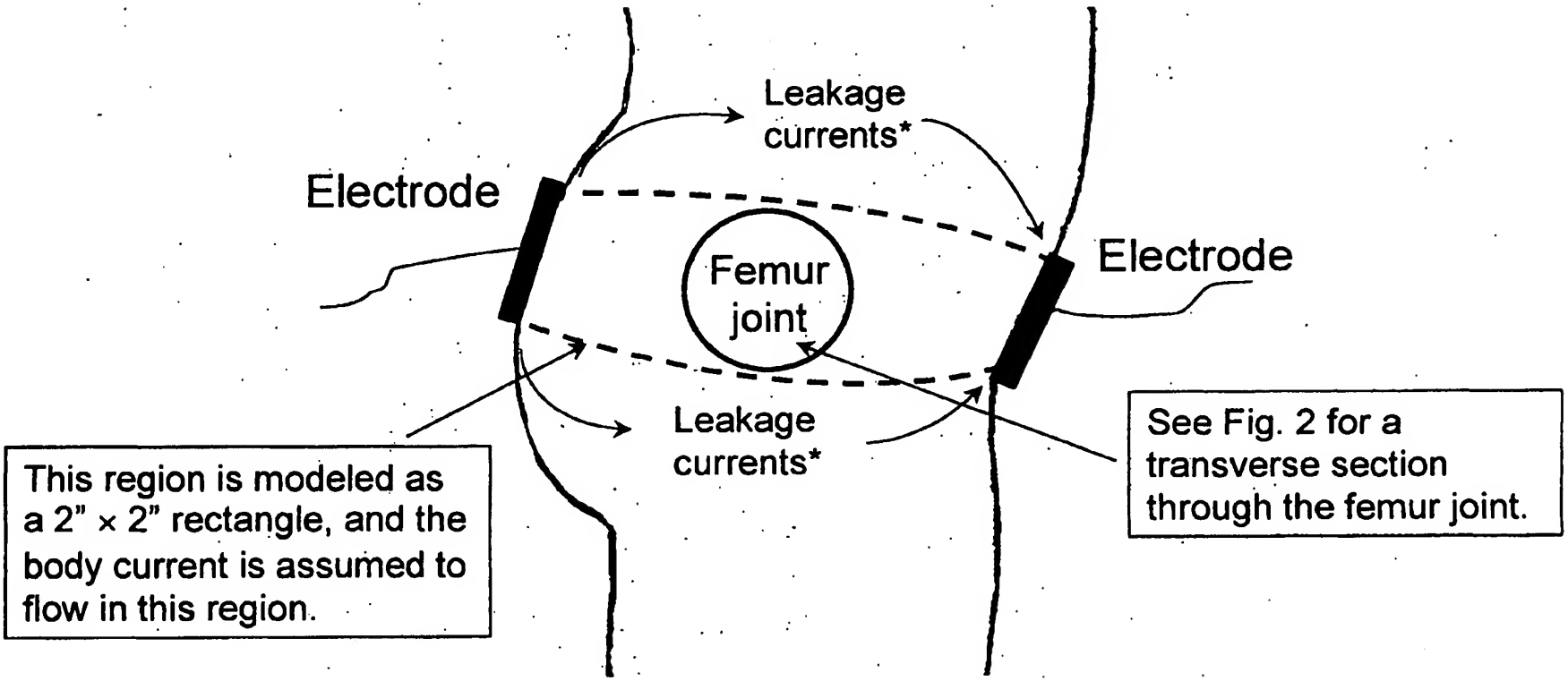

Electrode
Skin impedance
Circumferential fat layer impedance
Body current
Circumferential current in fat layer
Skin impedance
Electrode
Device current
Leakage impedance
Leakage current

FIGURE 5



*Leakage currents as shown in Figures 3A and 4 include circumferential flow in the fat layer, and body currents outside of the 2" × 2" rectangle. The current flow and impedance through the dashed region are those shown in Figure 3B.

Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/US04/037926

International filing date: 12 November 2004 (12.11.2004)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/520,088
Filing date: 14 November 2003 (14.11.2003)

Date of receipt at the International Bureau: 22 December 2004 (22.12.2004)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

World Intellectual Property Organization (WIPO) - Geneva, Switzerland
Organisation Mondiale de la Propriété Intellectuelle (OMPI) - Genève, Suisse